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A geographical information system for some Mediterranean benthic communities

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Abstract. This paper describes a regional geographical information system (GIS) for some Mediterranean benthic communities. The area covered by the GIS lies between the cities of La Ciotat and Giens in southeast France. The distinctive characteristics of this GIS compared with others usually described in the literature, are that all its layers describe the same theme but as seen at different moments with different scales and techniques used by different oceanographers. A method was devised to synthesize, on a pixel basis, the content of all these layers. Each pixel within each layer is weighted with a function relating to the year of survey, the sampling technique and the scale of the original map corresponding to that layer. The synthesis map is composed of the highest weighted values found in the set of layers. Also at each pixel, conflicts between the contents of layers are quantified and mapped.

1. Introduction

The Mediterranean benthic communities have been mapped by a number of oceanographers. Different sampling techniques and tools were, and still are, used for such mapping, namely airborne surveys, direct submarine observations and bionomic analysis of samples obtained by dredging (Cuvelier 1976, Cuvelier-Kareth 1979, Meinesz *et al.* 1981, Augier 1982). Most maps use the geographical grid either of the Service Hydrographique et Océanographique de la Marine (SHOM) of the French Navy on a Mercator projection, or of the Lambert III projection of the Institut Géographique National. Other maps are drawn directly from airborne surveys without any geometrical correction and so display variations in scale within the map. Within the same area many maps usually exist which differ for the reasons given above. Although of the same area, the maps produced by individual authors depend strongly upon the observation techniques used. In addition the mapping process requires methods of interpolation which make use of *a priori* knowledge which, in turn, depends upon the author of the map. Furthermore, the same objects depicted in two different maps are often classified differently because of a lack of standardized codes. Lastly, these maps are generally found in reports of restricted circulation which are difficult to access. For all these reasons these different sources of information are not fully used by the scientific communities.

A few syntheses of such information have already been made for French or Italian Environmental Agencies (Bellan *et al.* 1980, Jeudy de Grissac *et al.* 1986, Morri *et al.* 1986) but the authors were quite dissatisfied with the manual methods of handling the maps. To meet the demands of these agencies, a low-cost geographical information system (GIS) was designed which makes use of a personal computer. In devising a new

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method to synthesize the information, we faced an unusual problem. Rather than dealing with different thematic layers as a GIS usually does, each layer of our GIS displays the same theme but as seen differently (in terms of time and technique) within each layer. Much of the information is therefore either redundant or conflicting. In this sense, we may consider the mapping of the benthic communities as a random variable masking a natural evolution if present where each pixel is a representation of this random variable. The aim of our method is to synthesize the contents of the layers according to constraints which depend mainly upon the date, the measurement techniques and the scale of the original map corresponding to that layer. Since the construction of the GIS has already been presented by Méaille *et al.* (1988), this paper briefly describes the GIS and concentrates on the method of synthesis.

2. Description of the GIS

The area under study is located in southeast France, between the cities of La Ciotat and Giens (figure 1). The geometric grid used for the GIS is the Lambert III projection and the reference map at the selected scale of 1/25 000 is provided by the Institut Géographique National. Such characteristics are in agreement with the GIS developed within the CORINE Programme of the Commission of the European Communities (Rhind *et al.* 1986). The pixels are $25 \times 25\,m^2$. In this area the existing maps have been listed by Jeudy de Grissac *et al.* (1986). Maps drawn at a scale larger than 1/14 000 or smaller than 1/122 000 have not been used, nor have redundant maps or very old maps (prior to 1960). Twenty six maps have been retained with a variable number of classes. A total of about one hundred class names have been used although the contents are often similar but with different names. Following the definitions and recommendations of Pérès and Picard (1964), only twenty-five classes were retained, gathered into ten groups (table 1). Of these two classes and two groups correspond to unmapped areas and lands. The class codes were chosen according to the definitions of Pérès and Picard (1964) and Meinesz *et al.* (1983).

After the standardization of the classes, the maps were manually digitized as polygons by means of a digitizing table linked to a personal computer. The digital maps were then modified to fit the reference map using polynomial geometrical models calculated by standard landmark correlation techniques. The total area is divided into

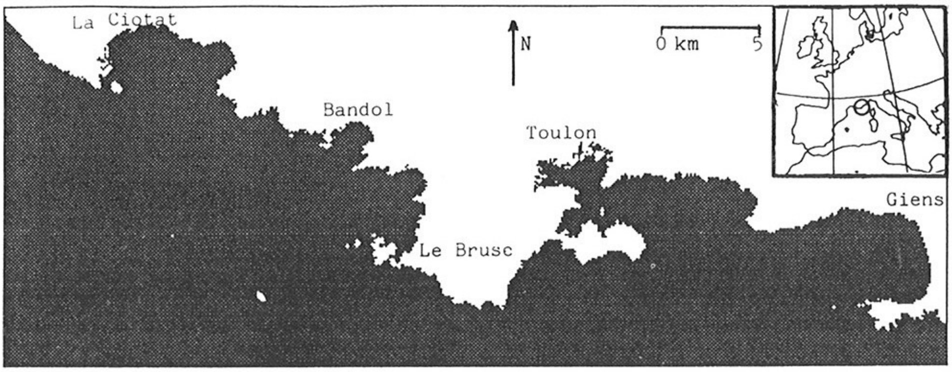

Figure 1. Map of the area under study.

Table 1. Correspondence between the codes (numbers and letters) and the classes and groups of the benthic communities.

Code	Class	Group
0:	Unmapped area	Unmapped area
1:AP	Photophilic algae	
2:APd	Degraded photophilic algae	Photophilic algae
3:APe	Photophilic algae on submarine scree	
10:P	Port, highly polluted area	Port
11:SVMC	Muddy sand in quiet areas	
12:SVMC/z	*Zostera Noltii* meadows on SVMC	Benthic communities within muddy sand
13:SVMC/c	*Cymodocea Nodosa* meadows on SVMC	
17:V+C	Coastal mud	
20:SFHN	Sand	
21:SFBC	Sand	Communities within littoral sands
22:SGCF	Raw sand influenced by bottom currents	
30:HP	*Posidonia Oceanica* meadows	
31:HPD	Degraded *P. Oceanica* meadows	*Posidonia Oceanica*
32:MM	Dead *P. Oceanica* meadows covered by photophilic algae	
40:C	Coralligeneous sediments	Benthic communities within
41:PC	Pre-coralligeneous sediments	coralligeneous areas
50:DC		
51:DC/c		
52:DC/p	Various types of coastal detritus	Communities within coastal detritus
53:DC/m		
54:DC/i		
60:DE		
80:DL	Offshore detritus	Communities within offshore detritus
250:COTE	Land	Emerged area

eight sectors. Each sector has a size equal to, or less than, 440 columns by 360 rows, numbers compatible with the most commonly-used graphic boards for personal computers. Each sector overlaps its neighbours and is composed of the set of the maps describing it. The GIS can easily be extended to a larger area by creating new sectors which need not necessarily be adjacent to the initial area.

The GIS offers features in data management, processing and display and makes most use of the Minimage® image processing software. It is implemented on an IBM PC compatible personal computer. Data are stored in a raster format on a WORM type (Write Once Read Many) optical disk. Various standard graphic boards are supported ranging from low (200 × 200, 16 colours) to higher resolution (1024 × 1024, more than one million colours). The raster format was chosen for the easier management of the weighting coefficients which are allocated to each pixel of each layer (see next section) and also for the subsequent use of multispectral high-resolution data of the space-borne sensors of the next decade.

3. Synthesis of the GIS content

Three different methods have been devised to synthesize the content of the GIS. The first two have already been discussed by Méaille *et al.* (1988) and this paper deals only with the third, which has been found to be most satisfactory at present. Each method produces maps of synthesis and maps of conflict or disagreement between the contents of the layers. It also makes use of the concept of credit or weight. These weights range from 0 to 20. They are allocated manually to each pixel of each layer and can be subsequently modified by the user. They depend upon heuristic rules derived from the cartographic errors, the scale of the original maps, the bathymetry and also the sampling techniques, such as airborne surveys, direct submarine observation or bionomic analyses of samples obtained by dredging (table 2). For example, airborne survey is efficient only for depths of less than 35 m in the area under study (Boudouresque and Meinesz 1982) and maps compiled by this technique are extrapolated for greater depths. Furthermore, although the boundaries of the benthic communities are accurately mapped with this technique in shallow waters, the communities cannot be precisely labelled from an aerial view and external knowledge is required to compile the map. In contrast, the dredging technique provides accurate results about the communities themselves but their limits must be inferred by extrapolation. The synthesis also takes into account the age of each map. When a pixel corresponds to different communities in two or more layers of similar weight, precedence is given to the most recent map.

The method of synthesis uses the theory of fuzzy sub-sets (see, e.g., Kaufmann 1977 or Zadeh 1965). In the usual theory of boolean sets (non-fuzzy) a point x within a universal set X belongs to a sub-set A or to its complement. This membership is defined by the characteristic function of the boolean sub-set A. This function has the value 1 if, and only if, the point x belongs to A and the value 0 if not. In our case X is the universal set defined by the geographical area, x is a pixel and A is a class, or group, which is a

Table 2. Table showing some key values of the weighting coefficients and their meanings. Intermediate values are used for intermediate cases.

Weight	Meaning
0	Unmapped area.
4	Credit is null. Mapping is not substantiated.
8	Credit is questionnable. Mapping is somewhat substantiated. (For example, if within an area the deepest observed limit of *Posidonia Oceanica* is 30 m, then assuming that this limit follows this isobath offers a rather good approximation.)
12	Average credit.
16	Very good credit.
20	Full credit. Mapping error less than one pixel.

sub-set of X. The union of two sub-sets, A and B, is also defined by its characteristic function which takes the value 1 if, and only if, the pixel belongs to A or B or both and the value 0 if not. As for the intersection of A and B, its characteristic function has the value 1 if, and only if, both characteristic functions of A and B are 1, i.e., if, and only if, the pixel x belongs to both sub-sets, and the value 0 if not.

In the theory of fuzzy sub-sets, the characteristic function is no longer 1 or 0 but a value between 0 and 1 which defines the plausibility (or probability) for a pixel x within a layer of belonging to a class A and is equal to the weight alloted to this pixel once normalized. The union and intersection operations are now defined in terms of this new characteristic function as: (*a*) union of fuzzy sub-sets: its characteristic function is now equal to the greatest characteristic function of each sub-set; (*b*) intersection of fuzzy sub-sets: its characteristic function is now equal to the smallest characteristic function of each sub-set.

The contents of the layers are now synthesized on a pixel basis. Firstly, each class (or group) is considered as a fuzzy-set within a layer and for each class (or group) the union is made over the layers. It provides a fuzzy sub-set of class for each class (or group) which indicates the maximum spatial extension of this class as well as the maximum corresponding weights per pixel. As an example, if A is a class, the characteristic function of A is composed at each pixel of the greatest plausibility observed for this class over the layers. Secondly the union of these fuzzy sub-sets of classes (or groups) is made, providing the synthesis map. At each pixel the class (or group) of which the plausibility is greatest is retained. Such a map is presented in figure 2. This method is a translation of the manual method of producing a synthesis map.

The maps of conflict or disagreement are computed using the intersection operator. The intersection of two fuzzy sub-sets of class (or group) indicates those pixels where conflict occurs. The resulting fuzzy sub-set is called the intersection sub-set. The magnitude of the conflict between both classes increases as the characteristic function of the intersection sub-set increases. A global map of conflict is then computed which shows at each pixel the largest conflict between the synthesis and the layers. It is obtained by forming the union of all the possible intersection sub-sets by taking each pair of classes (or groups) among the twenty-three classes of biocoenoses (or the corresponding eight groups). This computation provides two maps, both indicating the locations of conflict. One shows for each pixel which pair of classes presents the largest conflict and the other reports the magnitude of the disagreement (figure 3). Of course, other partial conflict maps can be computed by forming the union of a selected number of intersection sub-sets. This allows a very extended study of the conflicting cases to be made. It may also give some clues about how the maps are drawn and the implicit assumptions made by a particular oceanographer while creating a map.

4. Discussion

The first benefit of this GIS is, of course, the collection of maps of the area under study. Once the data are stored on an optical digital disk, they are easily accessible. Using them is also more efficient because the maps are in the same geographical frame, can be superimposed and are therefore readily comparable.

Geographical information systems are usually composed of layers of data which differ from each other in terms of themes. Our GIS takes into account twenty five classes and is composed of layers of data which are representations of the same theme:

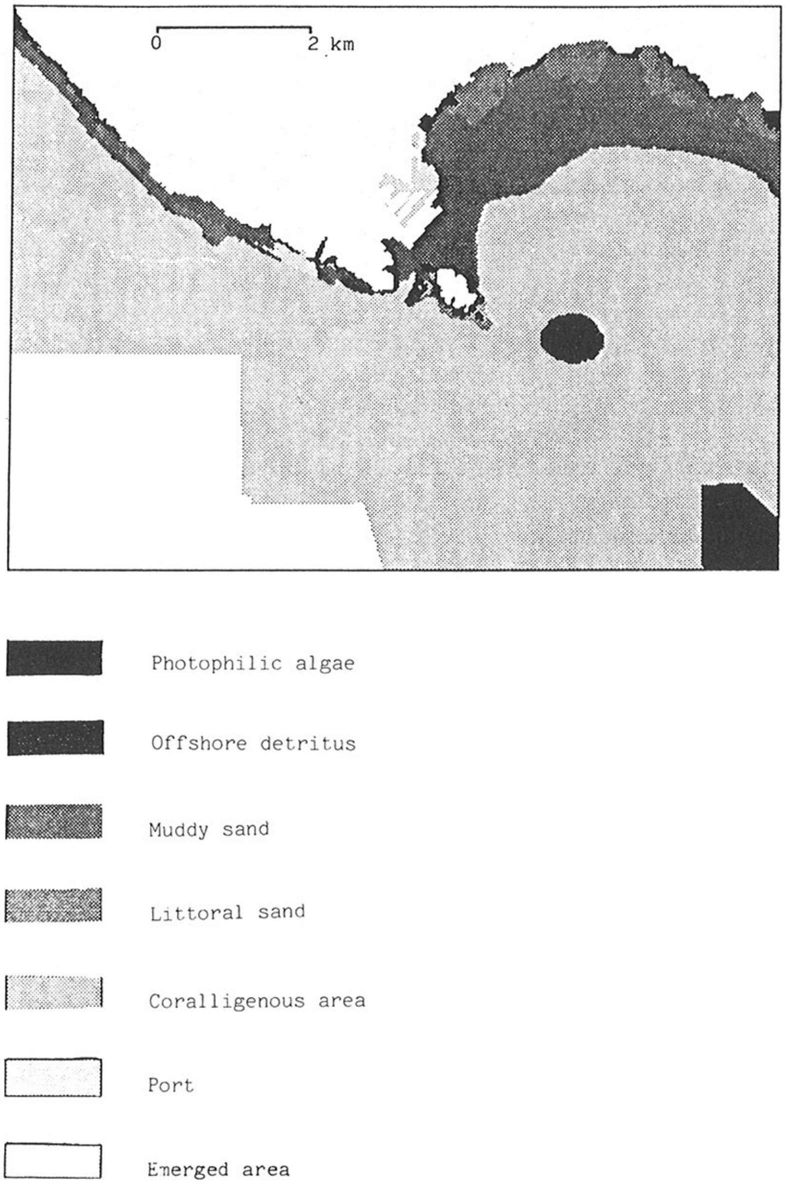

Figure 2. Synthesis map of the groups of benthic communities for the sector of La Ciotat.

the Mediterranean benthic communities. This GIS has been considered as a set of representations of a random function.

A method has been presented which shows how a suite of maps differing in scale and content can be reconciled. A map synthesizing the content of the GIS is generated by choosing at each pixel the class which presents the largest weight within the set of layers. In this sense the method of synthesis can be seen as a computerized translation of the manual method of producing a synthesis map or as a computer-aided method for the production of the map. Such a map provides information about the spatial

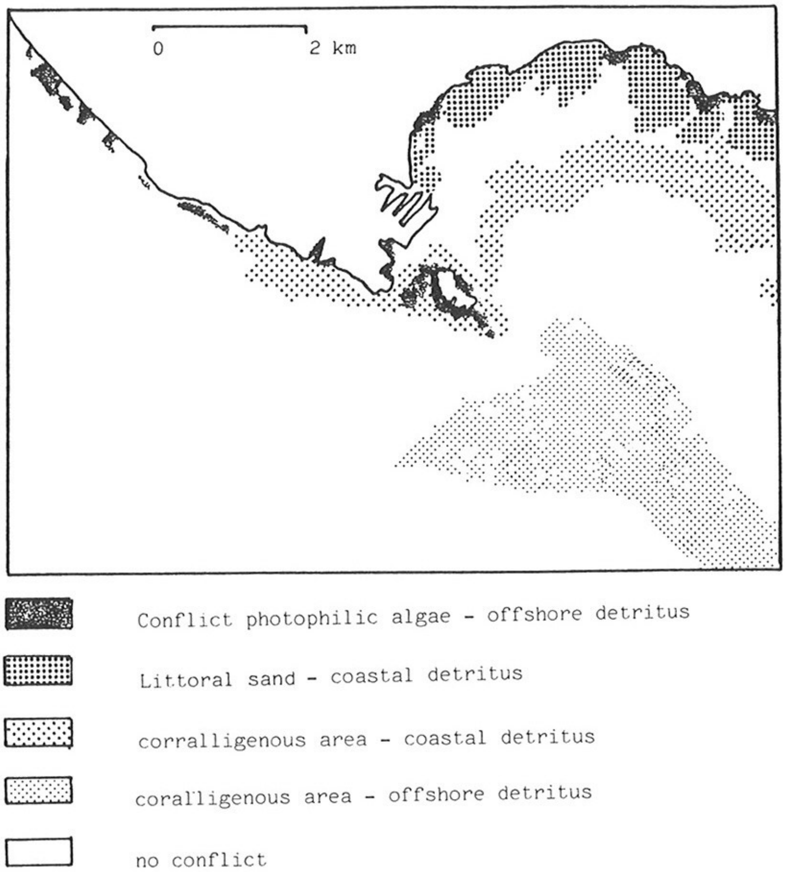

Figure 3. Map of the kind of greatest conflict between the layers and the synthesis map for the sector of La Ciotat.

distribution of the benthic communities and their interactions. It is of great help to the development of comprehensive models of these biocoenoses. If enough maps are available such an analysis can be made over successive periods of time and permit the evolution of the communities over time to be described.

Also of great interest are the maps of conflict which are not provided by standard manual analysis. These provide quantitative information about the accuracy of the synthesis by indicating where conflict occurs, its nature and its magnitude. They are also useful in reporting areas where there is a lack of accurate information and where subsequent investigations are needed. They are therefore a tool for the planning of campaigns of measurement.

Some improvements can be made to the method presented in this paper. Particular effort must be directed to the determination of the weight alloted to each pixel within each layer. This determination is the key element of the method and is currently made in a heuristic fashion. To overcome this drawback, work is underway involving the use of artificial intelligence techniques. It is intended to gather the knowledge of oceanographers and to express it in the form of laws and propositions to infer a value for the weight. Some objective criteria must then be found which relate these laws to the weights. Beyond the parameters already taken into account (measurement techniques, original scales, cartographic errors, age, bathymetry), others will be considered, such as sedimentology and spatial relationship between communities. If successful this approach will not only permit an automatic determination of the weights but also allow them to be changed as knowledge of the benthic communities is updated.

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